

## CHAPTER 9

## CIRCUIT MEASUREMENT

## INTRODUCTION

This chapter explains the basics of circuit measurement. It covers devices used to measure voltage, current, resistance, power, and frequency. This chapter does not cover all the available testing instruments. Instead, it describes those instruments most commonly found on Army watercraft.

Because of the high cost of repair and replacement parts, the marine engineman/engineer must correctly diagnose and repair defects in electrical equipment. With the correct choice of meters, it is possible to determine any circuit values needed to troubleshoot the electrical system.

This chapter uses schematic symbols and schematic diagrams to explain terms. Many of these schematic diagrams represent a meter in the circuit, as shown in Figure 9-1.

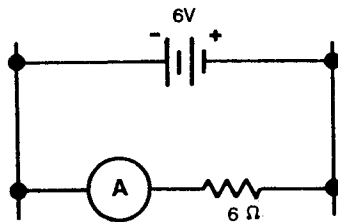


FIGURE 9-1. A Simple Representative Circuit.

The current in a DC circuit with 6 volts across a 6-ohm resistor is 1 ampere. The circled A in Figure 9-1 is the symbol of the ammeter. An ammeter is a meter used to measure current in amperes. Thus, it is an ampere meter, or ammeter. The ammeter in Figure 9-1 is measuring a current of 1 ampere with the voltage and resistance values given.

The quantities in an electrical circuit (voltage, current, and resistance) are important. By measuring the electrical quantities in a circuit, it is easier to understand what is happening in that circuit. This is especially true when troubleshooting defective circuits. By measuring the voltage, current, and resistance, the reason the circuit is not doing what it is supposed to do can be determined.

## IN-CIRCUIT METERS

Some electrical devices have meters built into them. These are in-circuit meters, which monitor the operation of the circuit in which they are installed. Some examples of in-circuit meters are the generator or alternator meter on some automobiles; the voltage, current, and frequency meters on ship switchboards; and the electrical power meter that records the amount of power consumed in a building.

It is not practical to install an in-circuit meter in every circuit. However, it is possible to install an in-circuit meter in each critical or representative circuit to monitor the operation of a piece of equipment. A mere glance at an in-circuit meter on a control board is often sufficient to tell if the equipment is working properly. It is important to become familiar with in-circuit meter values during all facets of the system operation. Only after observing familiar "normal" readings can an engineer readily identify abnormal system operation.

An in-circuit meter will indicate when an electrical device is not functioning properly. The cause of the malfunction is determined by troubleshooting, the process of locating and repairing faults in equipment after they have occurred.

## OUT-OF-CIRCUIT METERS

In troubleshooting, it is usually necessary to use an out-of-circuit meter that can be connected to the electrical equipment at various testing points. Out-of-circuit meters may be moved from one piece of equipment to another. They are generally portable and self-contained.

## BASIC METER MOVEMENTS

There are many different types of meter movements. The first discussed below is based on the principle of interaction of magnetic fields.

## Compass and Conducting Wire

An electrical conductor in which current flows has a magnetic field generated around it. If a compass is placed close to the conductor, the compass will react to that magnetic field (Figure 9-2).

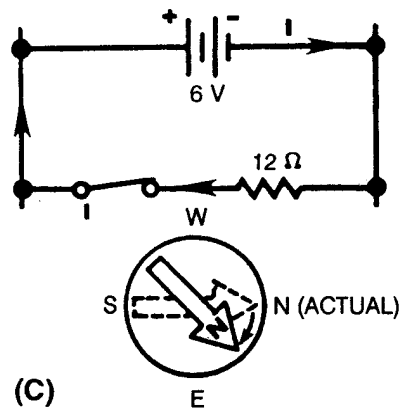
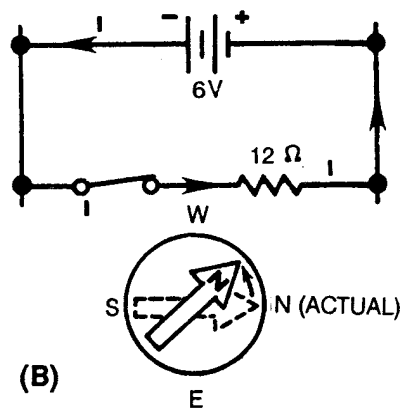
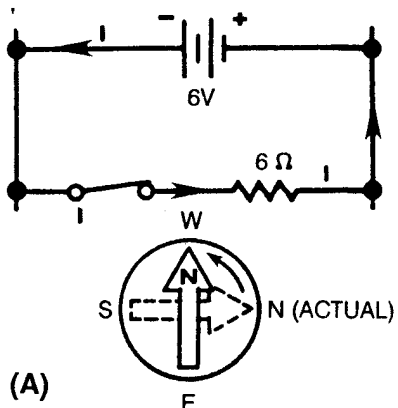


FIGURE 9-2. Compass and Conductor With Direct Current.

If the battery is disconnected, the north end of the compass will point to the south magnetic pole (located at the north geographic pole [Figure 2-10]). This is indicated by the broken line compass needle pointing to the right. When a battery is connected, current flows through the circuit, and the compass needle aligns itself with the magnetic field of the conductor, as indicated by the solid compass needle. The strength of the magnetic field created around the conductor depends on the amount of current. Because of the magnetic principle that unlike poles attract, a compass incorrectly identifies the North Pole as magnetic north. The North Pole of the earth is, in fact, the magnetic south pole.

In Figure 9-2 view A, the resistance in the circuit is 6 ohms. With the 6-volt battery shown, current in the circuit is 1 ampere. In view B, the resistance has been changed to 12 ohms. With the 6-volt battery shown, current in the circuit is 1/2 or .5 ampere. The magnetic field around the conductor in view B is weaker than the magnetic field around the conductor in view A. The compass needle in view B does not move as far from magnetic south.

If the direction of the current is reversed, the compass needle will move in the opposite direction because the polarity of the magnetic field has reversed. In view C, the battery connections are reversed; the compass needle now moves in the opposite direction.

A crude meter to measure current can be made using a compass and a piece of paper. To make a simple meter, use resistors of known values and mark the paper to indicate a numerical value (Figure 9-3). The first galvanometers were developed this way. A galvanometer is an instrument that measures small amounts of current. It is based on the electromagnetic principle.

The meter in Figure 9-3 is not very practical for electrical measurement. The amount the compass needle swings depends on the closeness of the compass to the conductor carrying the current, the direction of the conductor in relation to magnetic south, and the influence of other magnetic fields. In addition, very small amounts of current will not overcome the magnetic field of the earth, and the needle will not move.

The compass and conducting wire meter is a fixed conductor moving magnet device since the

compass is, in reality, a magnet that can move. The basic principle of this device is the interaction of magnetic fields: the field of the compass (a permanent magnet) and the field around the conductor (a simple electromagnet).

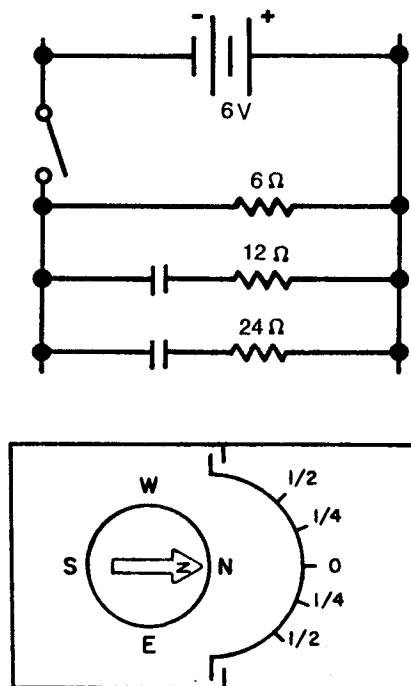


FIGURE 9-3. A Simple Meter From a Compass.

### Permanent Magnet Moving Coil Movement

A permanent magnet moving coil movement is based upon a freed permanent magnet and a coil of wire that can move, as in Figure 9-4. When the switch is closed, causing current through the coil, the coil will have a magnetic field that will react to the magnetic field of the permanent magnet. The bottom portion of the coil in Figure 9-4 will be the north pole of this electromagnet. Since opposite poles attract, the coil will move to the position shown in Figure 9-5.

The coil of wire is wound on an aluminum frame or bobbin. The bobbin is supported by jeweled bearings that let it move freely (Figure 9-6).

To use this permanent magnet moving coil device as a meter, two problems must be solved. First, a way must be found to return the coil to its original position when there is no current through the coil. Second, a method is needed to indicate the amount of coil movement.

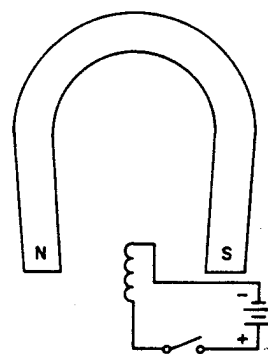


FIGURE 9-4. A Movable Coil in a Magnetic Field (No Current).

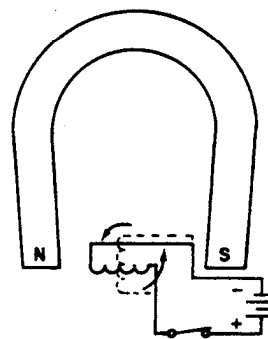


FIGURE 9-5. A Movable Coil in a Magnetic Field (With Current).

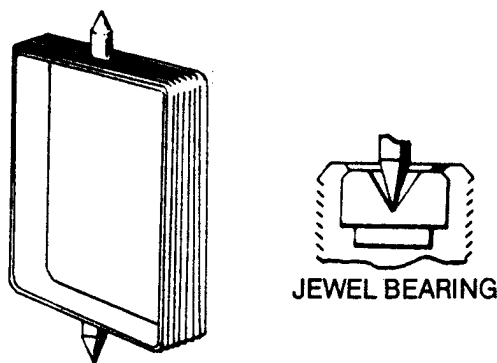


FIGURE 9-6. A Basic Coil Arrangement.

The first problem is solved by attaching hairsprings to each end of the coil (Figure 9-7). These hairsprings can also be used to make the electrical connections to the coil. By using hairsprings, the coil will return to its initial position when there is no current. The springs will also tend to resist the movement of the coil when there is current

through the coil. When the attraction between the magnetic fields (from the permanent magnet and the coil) exactly equals the force of the hairsprings, the coil will stop moving toward the magnet.

As the current through the coil increases, the magnetic field generated around the coil increases. The stronger the magnetic field around the coils, the farther the coil will move. This is a good basis for a meter.

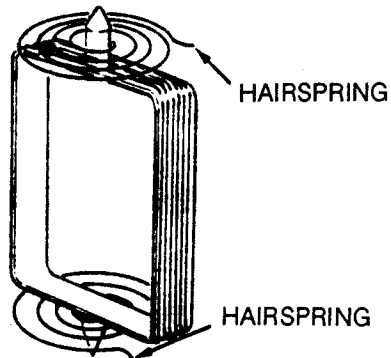


FIGURE 9-7. Coil and Hairsprings.

The second problem is solved using a pointer attached to the coil and extended out to a scale. The pointer will move as the coil moves. The scale can be marked to indicate the amount of current through the coil (Figure 9-8).

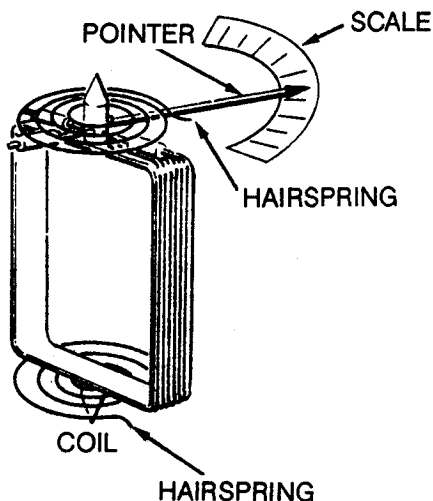


FIGURE 9-8. A Complete Coil.

Two other features are used to increase the accuracy and efficiency of this meter movement. First, an iron core is placed inside the coil to

concentrate the magnetic fields. Second, curved pole pieces are attached to the magnet to ensure the turning force on a coil increases steadily as the current increases. These same curved pole pieces are found in a motor.

Figure 9-9 shows the meter movement as it appears when fully assembled.

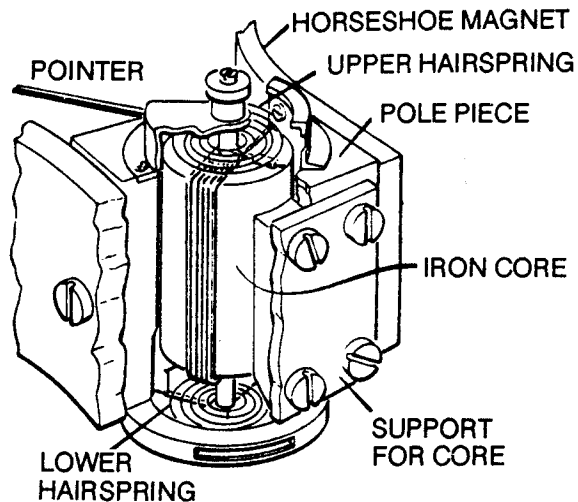


FIGURE 9-9. Assembled Meter Movement.

This permanent magnet moving coil meter movement is the basic movement in most analog (meter with a pointer indicator hand) measuring instruments. It is commonly called d'Arsonval movement because it was first employed by the Frenchman d'Arsonval in making electrical measurements. Figure 9-10 is a view of the d'Arsonval meter movement used in a meter.

### Compass and Alternating Current

Up to this point, only DC examples have been used. Figure 9-11 illustrates what happens when AC is used. It shows a magnet close to a conductor carrying AC at a frequency of 1 hertz. The compass needle swings toward the east part of the compass (down) as the current goes positive (view A). (The lower portion of the figure shows the sine wave of the current.) In view B, the current returns to zero, and the compass needle returns to magnetic south (right). As the current goes negative (view C), the compass needle swings toward the west portion of the compass (up). The compass needle returns to magnetic south as the current returns to zero (view D).

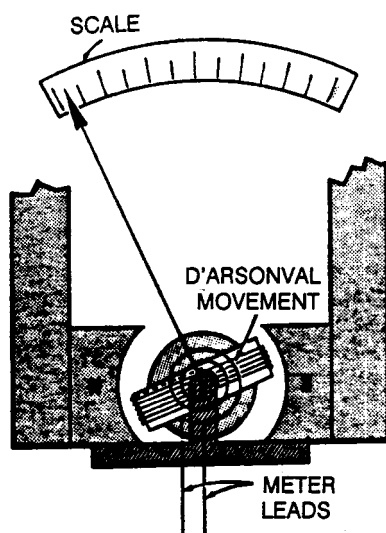


FIGURE 9-10. A Meter Using d'Arsonval Movement.

This cycle of current going positive and negative and the compass swinging back and forth will continue as long as AC is in the conductor.

If the AC frequency is increased, the compass needle will swing back and forth at a higher rate of speed. At a high enough frequency, the compass needle will not swing back and forth, but simply vibrate around the magnetic north position. This happens because the needle cannot react fast enough to the very rapid current alternation. The compass (a simple meter) will indicate the average value of the AC as zero. A device known as a rectifier is needed to let the compass react to the AC in a way that can be useful in measuring the current.

A rectifier is a device that changes AC to a form of DC. Figure 9-12 shows that an AC passing through a rectifier will come out as a pulsating DC.



FIGURE 9-12. Rectifier Action.

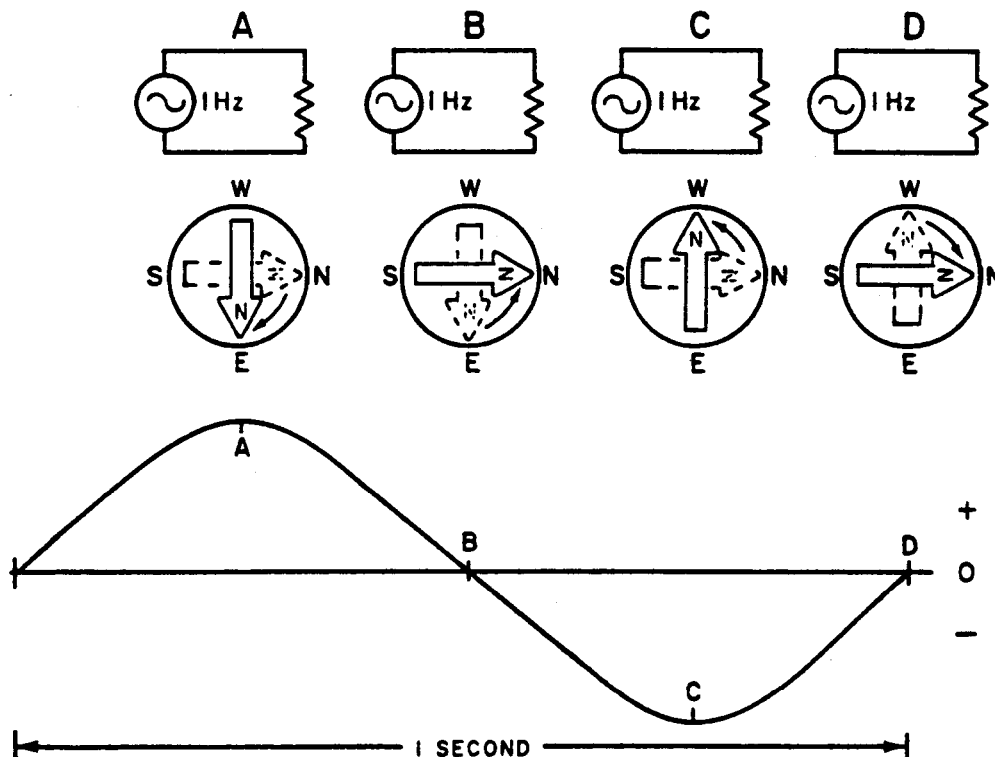


FIGURE 9-11. Compass and Conductor With Alternating Current.

Figure 9-13 shows what happens to the compass. When the compass is placed close to a wire and the frequency of the AC is high enough, the compass will vibrate around a point that represents the average value of the pulsating DC.

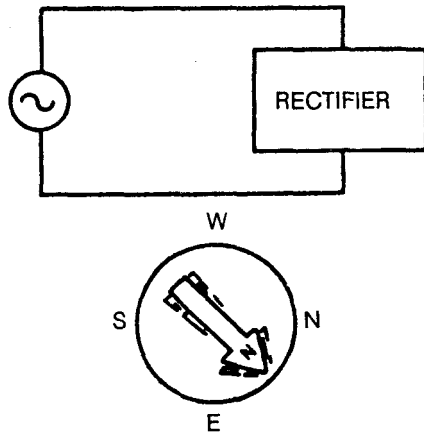


FIGURE 9-13. Compass and Conductor, Rectified AC.

Connecting a rectifier to a d'Arsonval meter movement creates an AC measuring device. When AC is converted to DC, the d'Arsonval movement will react to the average value of the pulsating DC, which is the average value of one-half of the AC sine wave. A d'Arsonval meter movement can indicate current in only one direction. If the d'Arsonval meter movement were used to indicate AC without a rectifier or DC of the wrong polarity, the movement would be severely damaged. The pulsating DC is current in a single direction, so the d'Arsonval meter movement can be used as long as proper polarity is observed.

Another problem encountered in measuring AC is that the meter movement reacts to the average value of AC. The value used when working with AC is the effective value (rms value). Therefore, a different scale is used on an AC meter. The scale is marked with the effective value, even though it is the average value to which the meter is reacting. That is why an AC meter will give an incorrect reading if used to measure DC.

## OTHER METER MOVEMENTS

The d'Arsonval meter movement (permanent magnet moving coil) is only one type of meter movement. Many other mechanical devices react to

electrical movement. The electrodynamic meter movement and the moving-vane meter movements also work on the principle of magnetism.

## THERMOCOUPLES

Chapter 2 described how an EMF could be developed from heat. As the dissimilar metals increased in temperature, the EMF increased proportionally. When an external circuit was connected to the dissimilar metals, current flow was established. During this process the thermocouple monitors temperature.

Many Army vessels use the thermocouple to monitor the main propulsion engine cylinder firing temperatures. Rather than have the meter face calibrated in current or voltage values, the meter face is calibrated in degrees Fahrenheit. As the cylinder temperature increases, there is an increase in current flow through the thermocouple. The current flow and temperature are directly proportional and will increase and decrease together.

## AMMETERS

An ammeter is a device that measures current. Since all meter movements have some resistance, a resistor will be used to represent a meter in the following explanations. DC circuits will be used for simplicity of explanation.

### Multimeter Ammeters Connected in Series

In Figure 9-14 view A, R1 and R2 are in series. The total circuit current flows through both resistors. The total circuit resistance  $R_t$  is —

$$R_t = R_1 + R_2$$

In view B, R1 and R2 are in parallel. The total circuit current does not flow through either circuit. The total circuit resistance  $R_t$  is —

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

If R1 represents an ammeter, the only way in which total current will flow through the meter (and thus be measured) is to have the meter (R1) in series with the circuit load (R2), as shown in view A.

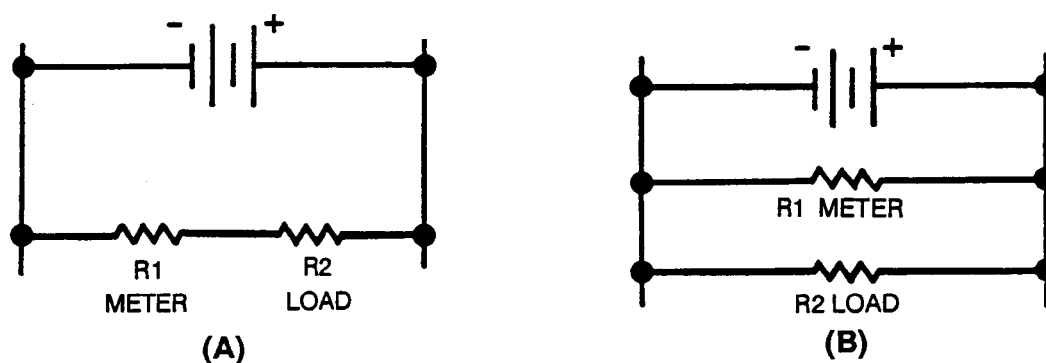


FIGURE 9-14. A Series and a Parallel Circuit.

In complex electrical circuits, you are not always interested in the total circuit current. You may be interested in the current through a particular component. In any case, an ammeter is always connected in series with the circuit that will be tested. Figure 9-15 shows various circuit arrangements with ammeters properly connected for measuring current in various portions of the circuit.

Connecting a multimeter ammeter in parallel with one of many electrical loads would give an incorrect reading. In this situation, current would be divided between the resistance in the loads and the very low resistance in the ammeter. It would not give the true total current moving through that section of the circuit.

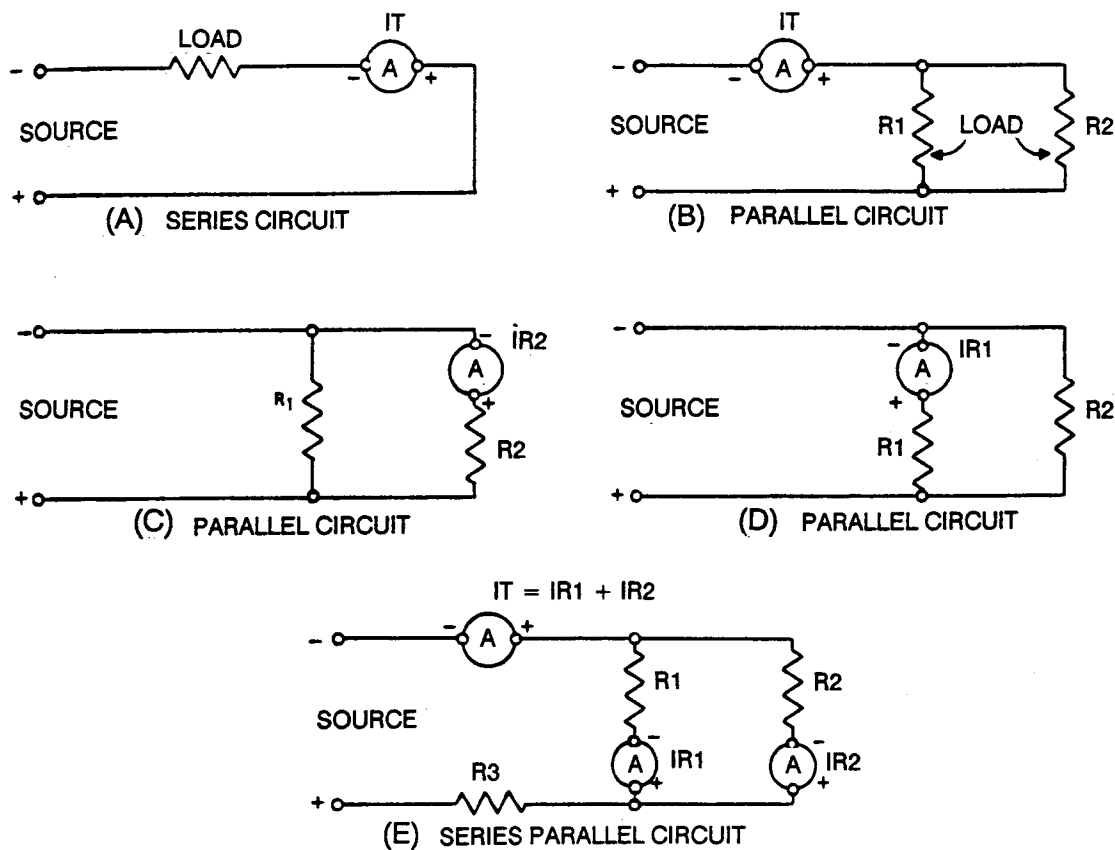


FIGURE 9-15. Proper Ammeter Connections.

Should the multimeter ammeter be connected across a constant potential source, such as the generator terminals, the minimal resistance in the ammeter would not be sufficient to restrict the majority of the generator's total current. This would be the equivalent of a shorted circuit. The excessive current draw through the meter movement would damage the meter. It may not be apparent at first, but if the ammeter is connected in parallel, across a higher resistance electrical load, a shorting situation results. Figure 9-16 shows a circuit. Figure 9-17 shows what happens when a meter is connected across the high-resistance load. Even though current is proportionally divided between the meter and the load in a parallel circuit, the extreme difference in resistance will put most of the generator's available current through the meter. The total resistance ( $R_t$ ) in a parallel circuit is always less than the smallest resistor. With less resistance in the circuit, an increased current will be delivered. Note the change in total current ( $I_t$ ) from the initial circuit in Figure 9-16 to the total current in Figure 9-17 with the addition of the improperly placed meter.



FIGURE 9-16. Initial Circuit.

$$E_t = 450 \text{ volts}$$

$$R_t = ?$$

$$I_t = ?$$

$$E_1 = 450 \text{ volts}$$

$$R_1 = 500 \text{ ohms}$$

$$I_1 = ?$$

( $R_1$  represents the electrical system loads. There is no meter connected in the circuit above.)

$$R_t = R_1$$

$$R_t = 500 \text{ ohms}$$

$$I_t = \frac{E_t = 450 \text{ volts}}{R_t = 500 \text{ ohms}}$$

$$I_t = .9 \text{ amps}$$

The high circuit resistance keeps current from the generator down. Figure 9-17 shows the ammeter placed improperly in the circuit.

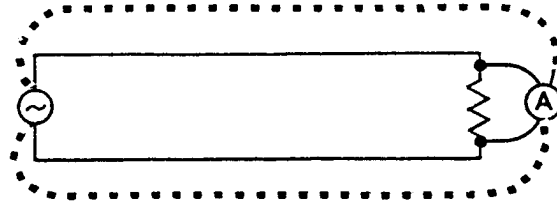


FIGURE 9-17. Improperly Placed Ammeter in Circuit.

$$E_t = 450 \text{ volts}$$

$$R_t = ?$$

$$I_t = ?$$

$$E_1 = 450 \text{ volts}$$

$$R_1 = 500 \text{ ohms}$$

$$I_1 = ?$$

$$E_a = 450 \text{ volts}$$

$$R_a = 4 \text{ ohms}$$

$$I_a = ?$$

Figure 9-17 shows the meter incorrectly connected across a constant potential source. To say that the meter is connected only in parallel with the load can be misleading. For all electrical purposes, the meter is connected directly to the generator terminals (dotted lines). Current takes the path of least resistance. In this situation, the generator current flow will respond to the minimal resistance of the meter and increase its current output.



The new total resistance ( $R_t$ ) of the circuit is found as follows:

$$R_t = \frac{R_1 \times R_a}{R_1 + R_a}$$

$$R_t = \frac{500 \text{ ohms} \times 4 \text{ ohms}}{500 \text{ ohms} + 4 \text{ ohms}}$$

$$R_t = 3.97 \text{ ohms}$$

The total resistance of this circuit has changed from 500 ohms to 3.97 ohms. With this drastic change in circuit resistance, generator current flow will increase accordingly:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{450 \text{ volts}}{3.97 \text{ ohms}}$$

$$I_t = 113.4 \text{ amps}$$

Use the circuit rules and Ohm's Law to determine how this new current is divided between the load and the meter:

The load:

$$I_1 = \frac{E_1}{R_1}$$

$$I_1 = \frac{450 \text{ volts}}{500 \text{ ohms}}$$

$$I_1 = .9 \text{ amps}$$

The current through the load has not changed.

The ammeter:

$$I_a = \frac{E_a}{R_a}$$

$$I_a = \frac{450 \text{ volts}}{4 \text{ ohms}}$$

$$I_a = 112.5 \text{ amps}$$

There is an excessive current flow through the meter.

Whenever you connect the ammeter portion of the multimeter, always break the circuit and connect your meter in series with the load. The small resistance of the meter is now added to the total electrical system loads ( $R_t$ ) and will only serve to slightly decrease the total generator current output.

### In-Circuit Ammeters Connected in Parallel

This section explains how in-circuit meters are connected in parallel for correct meter readings. This is another example of real-life applications of electrical circuit rules.

The ammeter in the instrument panel of the landing craft mechanized and the ammeters of many larger vessels are not designed to interrupt the electrical system they are monitoring. A device known as a shunt or parallel path is used. Physically small meters, monitoring hundreds of amperes, could not withstand that amount of current without burning up their meter movements. The shunt is a calibrated parallel path that allows the majority of current to bypass the meter. A shunt is a relatively heavy-gauge copper bar (Figure 9-18), readily able to conduct a great amount of current flow. The meter and the shunt are calibrated to each other so that the meter reacts to changes in current accurately. The shunt is always of a lesser resistance than the meter. Figure 9-18 shows how the shunt and ammeter are connected in the circuit.

If either the meter or the shunt are replaced separately, a component with the exact characteristics and ohmic value must be ensured. If an ammeter or shunt of a differing value is installed, the meter reading would not be accurate. It would change the relationship between the meter and its parallel path. Otherwise, the meter may actually show a system charging properly when, in actuality, the system is deficient.

Ammeters are also connected to current transformers so that the current through the meter maybe reduced accordingly. The same rules apply for replacing these current transformers and their meters that apply to the ammeter and its shunt.

Chapter 8 discusses the principles of current and voltage transformation.

### Effects on Circuit Being Measured

The ammeter affects the operating characteristics of the circuit. When the meter is installed, the generator's total current ( $I_t$ ) changes accordingly.

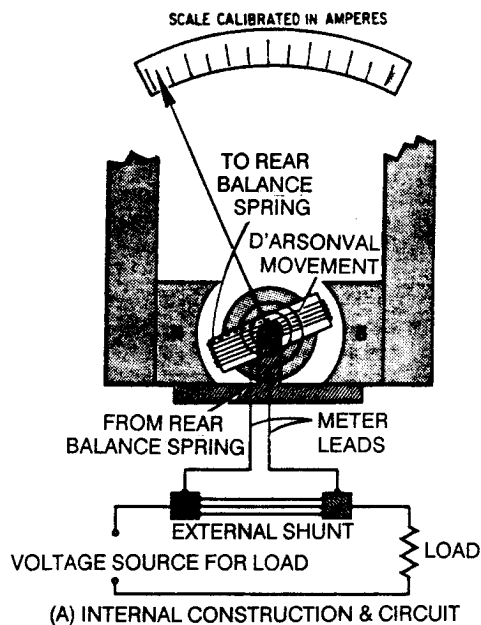
The current and voltage potential produced in the vessel's ship service generators are of such a large and deadly amplitude that a meter normally has minimal overall effects on the distribution system. However, like all components, devices, or conductors in the system, accumulative effects can be achieved. Conductor length, improper or corroded connections, and the introduction of meters (all otherwise insignificant loads) can contribute to an increased circuit resistance overall. For this reason, meter connections, as well as all device connections, must be made correctly to ensure conclusive troubleshooting practices. Under normal circumstances, the introduction of meters into a circuit is only a concern when printed circuitry is addressed.

### Ammeter Sensitivity

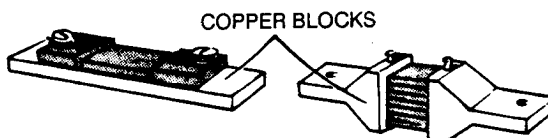
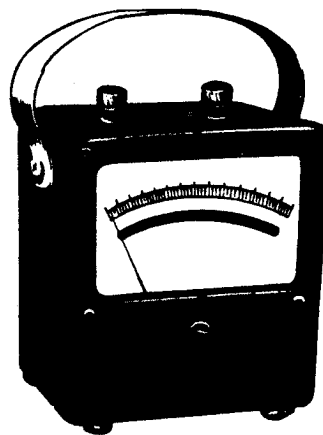
Ammeter sensitivity is the amount of current necessary to cause full-scale deflection (maximum reading) of the ammeter. The smaller the amount of current, the more sensitive the ammeter. For example, an ammeter with a maximum current reading of 1 milliamperes would have a sensitivity of 1 milliamperes. It would be more sensitive than an ammeter with a maximum reading of 1 ampere and a sensitivity of 1 ampere. Sensitivity ears be given for a meter movement, but ammeter sensitivity usually refers to the entire ammeter and not just the meter movement.

### Range Selection

Today's meters are extremely sensitive to the ranges and types of currents tested. Before any range selection is ever made, determine whether the circuits are alternating or direct current circuits. If the incorrect type of current is chosen, the meter will become damaged, or its fuse will open (blow). In either case, the meter will be rendered ineffective.



(B) EXTERNAL VIEW



(C) TYPICAL EXTERNAL AMMETER SHUNTS

FIGURE 9-18. An Ammeter Using the External Shunt.

The range switch is another very important part of the meter. To use the meter correctly, the range must be properly selected. If the current to be measured is larger than the meter scale selected, the meter movement will have excessive current and may become damaged. Therefore, it is important to always start with the highest range when using any meter.

If current can be measured on several ranges, use the range that results in a reading near the middle of the scale (Figure 9-19). This is important enough for digital meters to use bar graphs to indicate what percentage of the meter scale is in use.

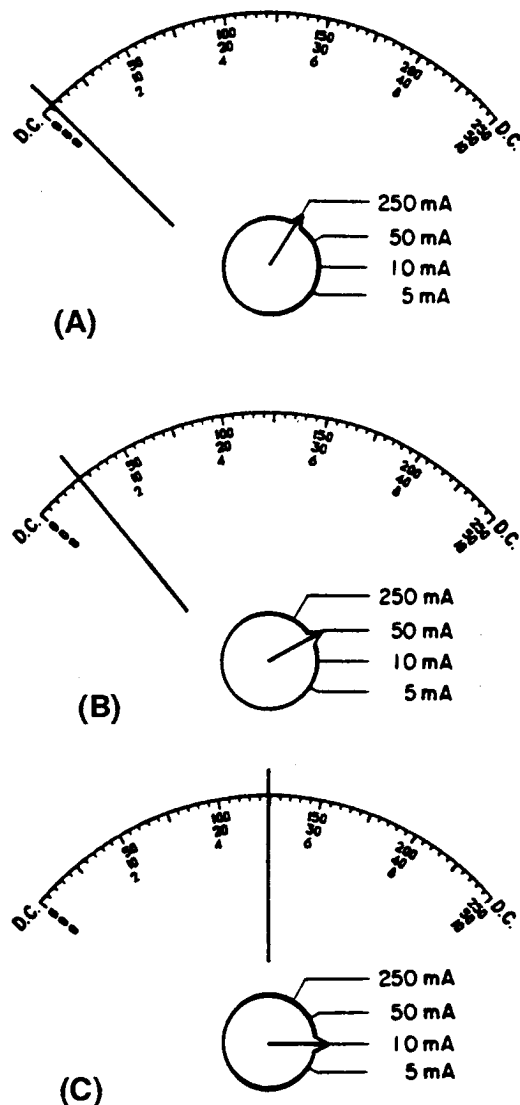


FIGURE 9-19. Reading an Ammeter at Various Ranges.

## Clamp-on Ammeter

The clamp-on ammeter (Figure 9-20) may be of the digital or the analog (movable needle) type. This meter is restricted to AC circuits. At the top of the meter is a set of jaws used to surround the wire being tested. The beneficial part of this meter is its ability to operate by detecting the magnetic field generated by the current moving in the conductor. This ability prevents the circuit from being opened and having to physically insert the meter. Current readings can also be taken from easily accessible locations in the circuit.

The clamp-on ammeter operates on the same principle that the transformer uses. The jaws of the ammeter are clamped around the conductor. The current-carrying conductor of the circuit being tested represents the primary winding. The jaws of the ammeter are the secondary winding. The current moving through the circuit generates its own magnetic field that surrounds the conductor. This AC magnetic field can induce a voltage and resulting current flow in the jaws of the ammeter.

The greater the current through the circuit conductor, the greater the magnetic field surrounding that conductor. Increased induction between the conductor and the ammeter means a greater current reading on the ammeter.

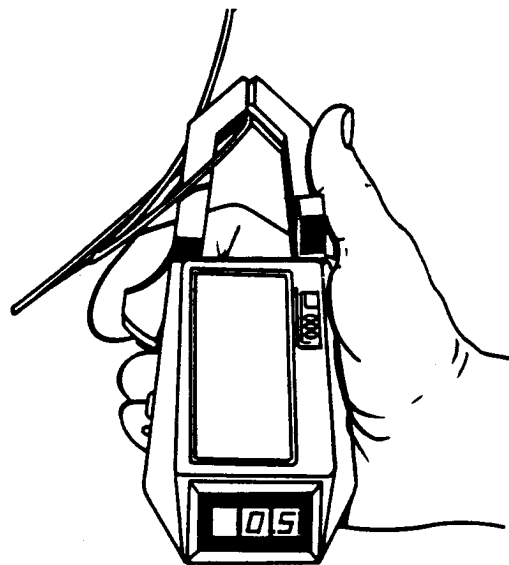


FIGURE 9-20. Clamp-On Ammeter or Induction Ammeter.

The conductor does not need to have the insulation stripped back. The only requirements for clamp-on ammeters are –

- The induction ammeter may only be used on AC systems. The DC electrical system does not have a constantly changing field. Therefore, without relative motion between the magnetic field of the conductor and the jaws of the induction ammeter, it is impossible to induce an EMF in the meter movement.
- The ammeter must measure one conductor at a time. If the ammeter jaws are encircling both wires of a two-wire electrical system, there will be no reading. The current traveling from the power source to the load sets up a magnetic field in one direction. The same current returning to the power supply from the load creates a magnetic field in the opposite direction. These two magnetic fields cancel each other out.

Digital clamp-on ammeters, or induction ammeters, are provided with a peak hold setting. This lets the user have the highest transient current reading displayed and maintained for a period of time. This becomes very important in electrical systems because of the fluctuating currents when motors are started.

When checking a circuit where the value of current is far below the lowest reading on the meter scale, the wire can be looped around the jaws of the ammeter. Doubling the conductor passes through the meter jaws doubles the magnetic field strength (Figure 9-21). Since only one wire is used, the current is traveling in the same direction and the magnetic field is doubled. Divide the meter reading by two. This also applies when looping the conductor any number of times through the jaws of the ammeter. Simply divide the current reading by the number of loops for the actual conductor current. This is an important concept because this type of setup is used in the current transformers of switchboards in Army Ships.

### Ammeter Safety Precautions

When using an ammeter, certain precautions must be observed to prevent injury to yourself and

others and to prevent damage to the ammeter or the equipment being serviced. The following list contains the minimum safety precautions for using an ammeter:

- Always connect multimeter ammeters in series with the circuit under test.
- Always start with the highest range on an ammeter (or any meter).
- De-energize and discharge the circuit completely before connecting or disconnecting the ammeter.
- In DC ammeters, observe the proper circuit polarity to prevent the meter from being damaged.
- Never use a DC ammeter to measure AC.
- Observe the general safety precautions of electricity.
- Ground all metal case meters to the hull of the ship. Many old metal case meters provide a grounding jack for this purpose.

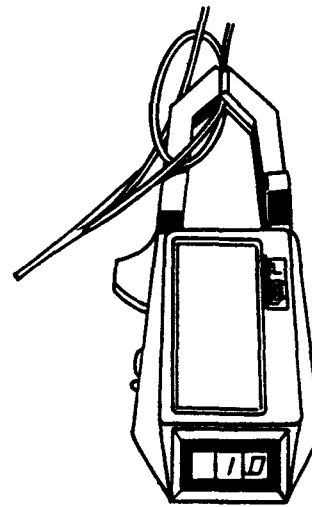


FIGURE 9-21. Ammeter Induction Effects Increased.

### VOLTMETERS

The voltmeter measures the voltage in a circuit or any EMF-producing component. The meter more

accurately measures any difference in potential between any two places to which the meter leads are connected.

### Voltmeters Connected in Parallel

Ammeters or their shunts are always connected in series with the electrical load. Voltmeters are always connected in parallel. Figure 9-22 and the following figures use resistors to represent the voltmeter movement. Since a meter movement can be considered as a resistor, the concepts shown are true for voltmeters and resistors. For simplicity, DC circuits are shown, but the principles apply to both AC and DC voltmeters.

When a voltmeter is connected across or parallel to a load, the measurement value indicates how much of the voltage was used up pushing current through the electrical load. Voltage is easily referred to as difference in potential here. Connecting the voltmeter across the terminals of a generator measures the difference in potential or the difference between the area where negative electrons are, as opposed to the area where they are not (the area of positive ions). If the same combination of negative electrons and positive ions were at each terminal of the generator, then there would be no difference in potential, or zero voltage.

To have a difference in potential, there must be an electron imbalance somewhere. When a generator is operating properly, negative electrons are excited. The negative electrons leave their atoms and accumulate at one terminal of the generator. Positive ions accumulate at the other terminal. Both these electrical particles have opposite magnetic polarities. As long as the generator keeps operating, the only way these negative electrons can recombine with the positive ions is through the electrical distribution system. Voltage is a measurement of how great the difference in potential is. The greater the difference in potential, the greater the force available to push the electrons to the positive ions.

When a load is placed in the circuit, its resistance determines how many electrons will be able to leave the negative terminal during any given period of time. Since a quantity of electrons exists on each side of the load, the difference between them is the difference in potential dropped from the original generator voltage source. If there is a high resistance, such as an open condition, then there would

be maximum electrons on one side of the load, and no electrons on the other side of the load. This would be a maximum voltage reading. A negligible resistance, such as a good fuse, would have the same amount of electrons on each side of the fuse element. There would then be no difference in potential and 0 voltage reading.

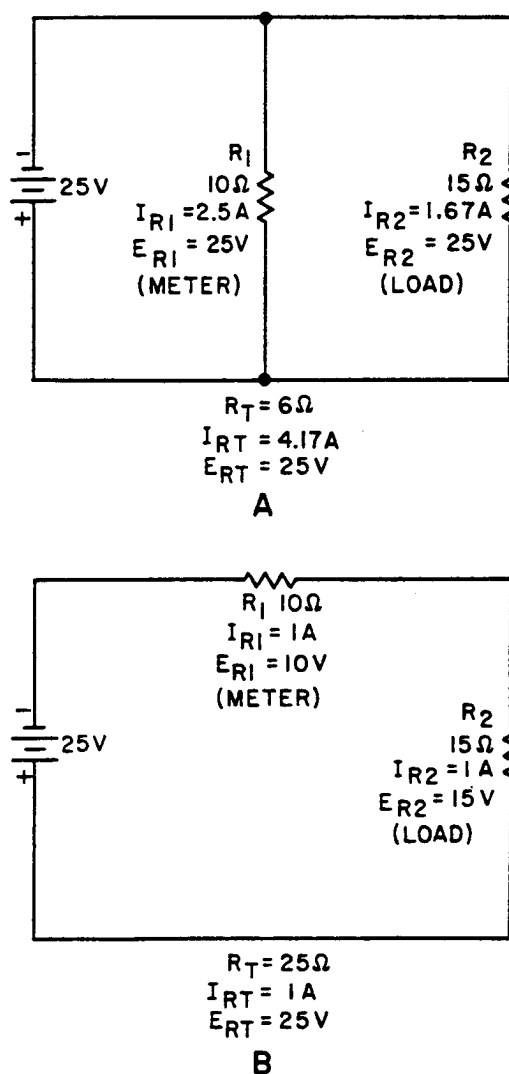


FIGURE 9-22. Current and Voltage in Series and Parallel Circuits.

A good example of this is the series circuit in Figure 9-23, which shows two loads in series with the generator. Place a voltmeter across the  $R_2$  load. Measure the difference in potential between the negative side of the  $R_2$  load and the positive side of the  $R_2$  load.

$$E_t = 120 \text{ volts}$$

$$R_t = ?$$

$$I_t = ?$$

$$R_1 = 10 \text{ ohms}$$

$$I_1 = ?$$

$$E_1 = ?$$

$$R_2 = 20 \text{ ohms}$$

$$I_2 = ?$$

$$E_2 = ?$$

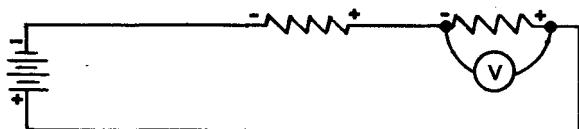


FIGURE 9-23. Voltage Drops.

To determine the electrical values, find the total resistance of the circuit ( $R_t$ ):

$$R_t = R_1 + R_2$$

$$R_t = 10 \text{ ohms} + 20 \text{ ohms}$$

$$R_t = 30 \text{ ohms}$$

Since this is a series circuit and current is constant, find the total current ( $I_t$ ) allowed to flow through the circuit in one second:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{120 \text{ volts}}{30 \text{ ohms}}$$

$$I_t = 4 \text{ amps}$$

Do not be concerned with the minimal influence the meter has on the circuit, but transcribe the current value to 11 and 12.

Using the voltmeter, there is a reading of 80 volts across the  $R_2$  resistance. By using Ohm's Law, verify this reading:

$$E_2 = I_2 \times R_2$$

$$E_2 = 4 \text{ amps} \times 20 \text{ ohms}$$

$$E_2 = 80 \text{ volts}$$

This is the difference in potential across the  $R_2$  resistance. When the meter is repositioned to read the voltage across  $R_1$ , a difference in potential between the negative side and the positive side of the resistance is registered. In this case, there are 40 volts. Figure 9-24 effectively shows the differences in potential.

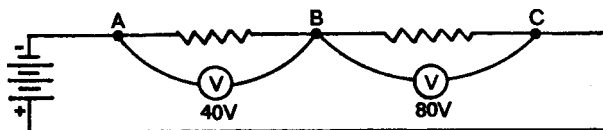


FIGURE 9-24. Differences in Potential.

SOURCE	120 V	80 V	0 V
VOLTAGE	A	B	C

$R_1$	$R_2$
$120 - 80 = 40$	$80 - 0 = 80$

At point A, there is full generator voltage available (120 volts). At point B, 80 volts are left. This means that the  $R_1$  resistance was sufficient enough to use up, or drop out of the circuit, 40 volts when moving 4 coulombs of electrons through the 10-ohm resistance in one second. At point C, no voltage is left after completing all the work pushing electrons through the resistances. The voltmeter does not read the points A or B or C, but rather a difference between points A and B as well as between points B and C. Since voltage is the potential force and a difference between each side of a resistor exists, a difference in the potential (or voltage) is recorded.

## Sensitivity of Voltmeters

Voltmeter sensitivity is expressed in ohms per volt (ohms/volt). It is the resistance of the voltmeter at full-scale reading in volts. Since the voltmeter's resistance does not change with the position of the pointer, the total resistance of the meter is the sensitivity multiplied by the full-scale reading. The higher the sensitivity of a voltmeter, the higher the voltmeter's resistance. Since high-resistance voltmeters have less loading effects on circuits, a high-sensitivity meter will provide a more accurate voltage reading.

## Voltmeter Safety Precautions

Just as with ammeters, voltmeters require safety precautions to prevent injury to personnel and damage to the voltmeter or equipment. The following is a list of the minimum safety precautions for using a voltmeter:

- Always connect voltmeters in parallel.
- Always start with the highest range of a voltmeter.
- In DC voltmeters, observe the proper circuit polarity to prevent damage to the meter.
- Never use a DC voltmeter to measure AC voltage.
- Observe the general safety precautions of electricity.

## OHMMETERS

The two instruments most commonly used to measure resistance are the ohmmeter and the megohmmeter (megger).

The ohmmeter is widely used to measure resistance and check the continuity of electrical circuits and components. Using an ohmmeter to determine continuity provides the engineer with information on the circuit's ability to conduct current. The ohmmeter is inaccurate below the 3- to 5-ohm level. Its range usually extends to only a few megohms.

The megger is widely used for measuring insulation resistance, such as between a wire and another surface on the other side of the insulation. The range of a megger extends to more than 1,000 megohms.

The ohmmeter consists of a DC ammeter, with a few added features. The added features are a DC source of potential (usually a 9-volt battery) and one or more resistors (one of which is variable). Figure 9-25 shows a simple ohmmeter circuit.

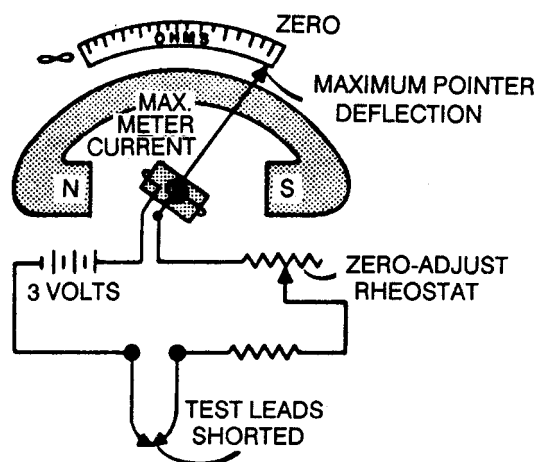


FIGURE 9-25. Simple Ohmmeter Circuit.

The ohmmeter's pointer deflection is controlled by the amount of battery current passing through the moving coil. Before measuring the resistance of an unknown resistor or component, the test leads of the ohmmeter are first shorted together (Figure 9-25). With the leads shorted, the meter is calibrated for proper operation on the selected range. While the leads are shorted, meter current is maximum, and the pointer deflects a maximum amount, somewhere near the zero on the ohms scale. Consult the manufacturer's manual to zero the ohmmeter. The AN/PSM-45 and AN/PSM-45A digital multimeter calibrates automatically when the test leads are shorted together. Analog meters have a variable resistor (rheostat) that requires manual adjustment to zero (with the test leads shorted together). When the test leads are separated, the meter should indicate infinity, or the meter's maximum resistance reading. Always turn the ohmmeter off when it is not in use to prevent the leads from accidentally discharging the meter battery.

## Ohmmeter Use

After the ohmmeter is adjusted for zero reading, it is ready to be connected in a circuit to measure resistance. Figure 9-26 shows a typical circuit and ohmmeter arrangement.

The circuit must always be de-energized. This prevents the source voltage from being applied across the meter, which could damage the meter movement.

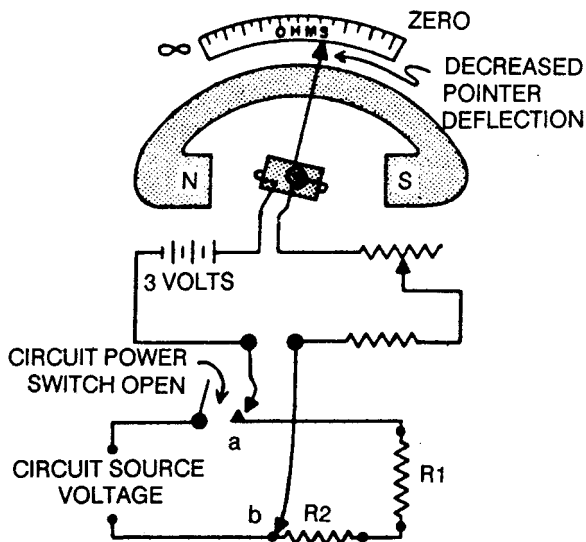


FIGURE 9-26. Measuring Circuit Resistance With an Ohmmeter.

The test leads of the ohmmeter are connected in series with the circuit to be measured (Figure 9-26). This causes the current produced by the 9-volt battery of the meter to flow through the circuit being tested. Assume that the meter test leads are connected at points a and b of Figure 9-26. The amount of current that flows through the meter coil will depend on the total resistance of resistors R1 and R2 and the resistance of the meter. Since the meter has been preadjusted (zeroed), the amount of coil movement now depends entirely on the resistance of R1 and R2. The inclusion of R1 and R2 raises the total series resistance, decreasing the current, and thus decreasing the pointer deflection. The pointer will now come to rest as a scale figure indicating the combined resistance of R1 and R2. If R1 and R2, or both, were replaced with resistors having a larger value, the current flow in the moving coil of the meter would be decreased further. The deflection would also be further decreased, and the scale indication

would read a still higher circuit resistance. Movement of the moving coil is proportional to the amount of current flow.

When using an ohmmeter in complicated circuits, the circuit must be disconnected at the component being checked. If other parallel paths are accidentally measured with the ohmmeter, the resistance reading will be less than the smallest resistance, providing an incorrect interpretation of the test results.

## Ohmmeter Ranges

The amount of circuit resistance to be measured may vary over a wide range. In some cases, it may only be a few ohms; in others, it may be as great as 1,000,000 ohms (1 megohm). To enable the meter to indicate any value being measured with the least error, scale multiplication features are used in most ohmmeters. There are various scale indicators for checking diodes and capacitors as well. The many different meters require the specific information attained from their technical manual. TM 11-6625-3199-14 is the reference for the AN/PSM-45A multimeter. This is required reading before trying to operate this multimeter.

## Ohmmeter Safety Precautions

The following safety precautions and operating procedures for ohmmeters are the minimum necessary to prevent injury and damage:

- Be certain the circuit is de-energized and **discharged before connecting an ohmmeter.**
- Do not apply power to a circuit while measuring resistance.
- When finished using the ohmmeter, switch it to the OFF position.
- Always adjust the ohmmeter for zero after you change ranges and before making resistance measurement.

## MEGOHMMETER

An ordinary ohmmeter cannot be used for measuring resistance of multimillions of ohms, such



as in conductor insulation. To adequately test for insulation breakdown, it is necessary to use a much higher potential than is furnished by the battery of an ohmmeter. An instrument called a megohmmeter (megger) is used for these tests. The megger is the most useful engineering tool for determining the condition of electrical insulation. Thus, it determines the condition of the electrical component and possible future operational readiness of the vessel.

In catastrophic cases, the insulation is burned off the conductor by excessive current heat. In this case, the component requires replacement. More often, the component insulation resistance is slowly reduced over a period of months. Proper monitoring of the major electrical components will provide information on the expected servicing requirements for the device. In this manner, major component maintenance can be projected ahead of time, instead of managed by crisis.

### Megger Construction

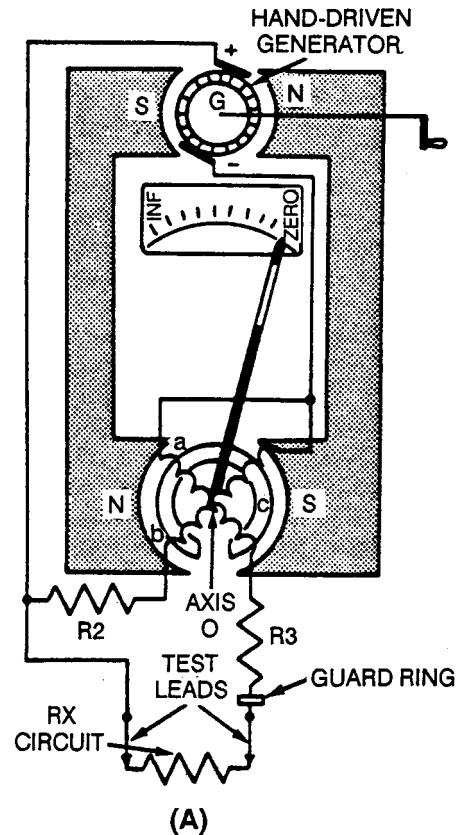
The megger (Figure 9-27) is a portable instrument that consists of two primary elements:

- A hand- or electric-driven DC generator (G). This supplies the necessary voltage for making the measurement.
- The instrument portion, which indicates the value of the resistance being measured.

The instrument portion is the opposed coil type, as shown in view A. Coils a and b are mounted on the movable member c, with a fixed relationship to each other, and are free to turn as a unit in a magnetic field. Coil b tends to move the pointer counterclockwise, and coil a tends to move the pointer clockwise.

Coil a is connected in series with R3 and the unknown resistance, Rx, to be measured. The combination of coil, R3, and Rx forms a direct series path between the positive (+) and negative (-) brushes of the DC generator. Coil b is connected in series with R2, and this combination is also connected across the generator. There are no restraining springs on the movable member of the instrument portion of the megger. Therefore, when the generator is not operated, the pointer floats freely and may come to rest at any position of the scale. When checking the megger for proper operation, isolate the two megger

leads from each other. Crank or operate the megger. There should be a maximum resistance or infinite resistance reading. Next, connect the two megger test leads to each other and operate the megger. The meter should indicate zero resistance. Do not touch the megger leads when the megger is being operated.



(A) A Megger Internal Circuit.

(B) An External View of a Megger.

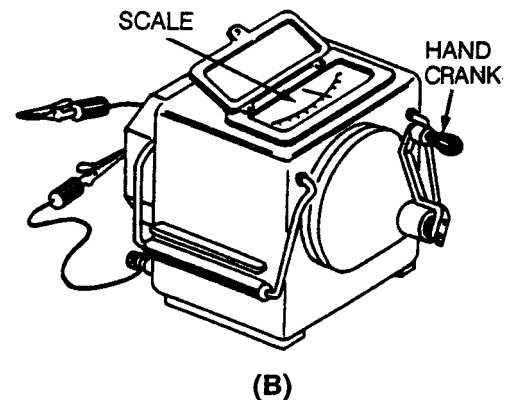


FIGURE 9-27. Megohmmeter.

## Megger Ratings

Army meggers are rated at 500 and 1,000 volts. To avoid excessive test voltages, most meggers are equipped with friction clutches. When the megger is cranked faster than its rated speed, the clutch slips, and the generator speed and output voltage are not allowed to exceed their rated value. When extremely high resistances (for example, 10,000 megohms or more) are to be measured, a high voltage is needed to cause sufficient current to flow to actuate the meter movement. For extended ranges, a 1,000-volt megger is available. Usually, meggers are only used on circuits with a normal voltage of 100 volts and up. When testing insulation, always refer to the appropriate TM or the manufacturer's recommendations.

## Megger Use

Motor windings and components are tested to ensure that the conductors are not coming in direct contact with their housing, frame, or other individual conductor turns because the insulation has been damaged. The difference in potential, provided by the 9-volt ohmmeter battery, may not be substantial enough to correctly indicate an insulation problem in a 450-volt electrical system. The 9-volt push may not be sufficient to bridge some damaged insulation. There would then be an indication of infinite (maximum ohms) resistance. What appears to be an acceptable insulation reading would, in fact, be inconclusive. The higher voltage of the 450-volt electrical system would have no trouble bridging the gap in the damaged insulation. The megger, available in 500- and 1,000-volt power supplies, would detect this damage in the insulation and measure the resistance required when pushing the current past the damaged section of insulation. The megger provides an accurate indication of electrical insulation under system operating conditions.

The ohmmeter does not allow a conclusive test for conductor insulation. This is because the small potential in the ohmmeter is not sufficient to force electrons across small distances or high-resistance insulation. For this same reason, the megger is not suitable for testing the continuity of a conductor. The higher potential of the megger would allow completed circuit readings where the low potential ohmmeter would detect defects in conductor continuity. The megger and the ohmmeter should always be used together when substantiating the condition of electrical components.

## Megger Testing

Many regulatory texts require the periodic testing of insulation. The Institute of Electrical and Electronic Engineers requires the additional testing of idle apparatus. A log book will be maintained for these megger resistance readings. As equipment ages and becomes contaminated with grease and dirt, the resistance of the insulation decreases. When these decreases in resistance are noted, preventive maintenance can be planned. Sometimes, cleaning alone will restore the insulation dielectric strength and return the component to operational condition. It is recommended that all major electrical components over 100 volts be megger tested every two years. Generators and critical electric motors can be megged before missions to evaluate and project their future operating condition.

As with the ohmmeter, the megger is never used on an energized circuit. Additionally, the megger is never used on a circuit in which solid state components cannot be isolated. The high potential of the megger will destroy rectifiers, voltage regulators, radio equipment, and other electronic equipment. Make sure that the electrical component undergoing testing is completely isolated from the rest of the circuit.

One megger test lead is connected to the de-energized conductor. The other megger test lead is connected to the noncurrent-carrying conductive material adjacent to the conductor's insulation. To test a cable, one test lead would go to the de-energized normally current-carrying copper conductor of a cable, and the other test lead would be connected to the noncurrent-carrying armor shielding. In another example, a megger lead could be connected to a motor winding lead, and the other megger test lead could be connected to the motor housing. In both of these cases, there should be no continuity. There should be a great deal of resistance between the current-carrying conductor and the housing with which the engineer is likely to come in contact.

The megger is then operated for a period of at least 30 seconds. Refer to the component manufacturer's information for the specific results of a test. However, if these specifications are no longer available, any change in the insulation resistance must be considered suspect.

## Megger Safety Precautions

When using a megger, observe the following minimum safety precautions to prevent injury to personnel or damage to the equipment:

- Use meggers on high-resistance measurements only, such as insulation measurements.
- Never touch the test leads when the megger is being operated.
- De-energize and discharge the circuit before connecting a megger.
- Disconnect the component being checked from other circuitry before using the megger.
- Use only on circuits with a normal voltage of 100 volts or greater.

## MULTIMETER

A multimeter is the most common measuring device in the Army. The name multimeter comes from multiple meter, and that is exactly what it is. It combines a DC ammeter and voltmeter, an AC ammeter and voltmeter, and an ohmmeter.

### Digital Multimeters

Several models of digital multimeters have been fielded for use in the Army. Always follow instructions for use in the applicable TMs. Digital multimeters have a display screen and give their readings as numerals on the screen, usually using liquid crystal display (LCD).

### Analog Multimeters

Analog multimeters are those with d'Arsonval movements using a needle and scale. Most analog multimeters have been replaced by digital multimeters, but the marine engineman/engineer may still be issued analog multimeters.

### Parallax Error

Analog multimeters have a mirror built into the scale to aid in reducing parallax error (Figure 9-28).

Parallax can be a problem when reading analog meters. To prevent improper meter value recognition, a mirror is placed just above the scale. When properly viewing the meter, the reflection of the pointer will not be seen. Although portable analog meters are being phased out, in-circuit analog meters are not. The problem of parallax is nowhere more evident than when paralleling AC generators. Even though some switchboard meters do not have a mirror, a perfect match of the voltage for each generator is required. Each of the two (or more) voltmeters must be viewed directly from the front to confirm exact voltage readings.

## FREQUENCY METERS

All AC sources are generated at a set frequency or range of frequencies. A frequency meter provides a means of measuring this frequency. Two common types of frequency meters are the vibrating reed frequency meter and the moving disc frequency meter.

### Vibrating Reed Frequency Meter

The vibrating reed frequency meter is one of the simplest devices for indicating the frequency of an AC source. It is used on power panels to monitor the frequency of AC. Figure 9-29 is a simplified diagram of one type of vibrating frequency meter.

The current, whose frequency is to be measured, flows through the coil and exerts maximum attraction on the soft iron armature twice during each cycle (Figure 9-29). The armature is attached to the bar, which is mounted on a flexible support. Reeds having natural vibration frequencies of 110, 112, 114 and so on up to 130 hertz are mounted on the bar (view B). The reed having a frequency of 110 hertz is marked 55 hertz. The one with 112 hertz is marked 56 hertz. The one with 120 hertz is marked 60 hertz, and so forth.

When the coil is energized with a current having a frequency between 55 and 65 hertz, all the reeds are vibrating slightly. But the reed having a natural frequency closest to that of the energized current whose frequency is to be measured vibrates more. The frequency is read from the scaled value opposite the reed having the greatest vibration.

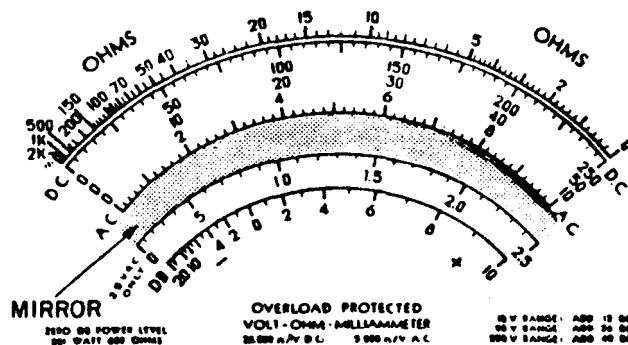


FIGURE 9-28. Analog Multimeter Scale With Mirror.

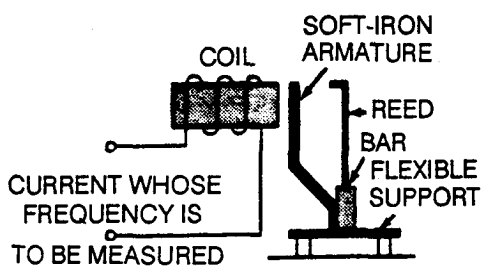
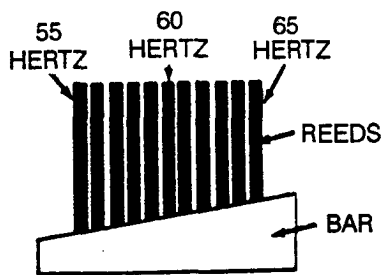
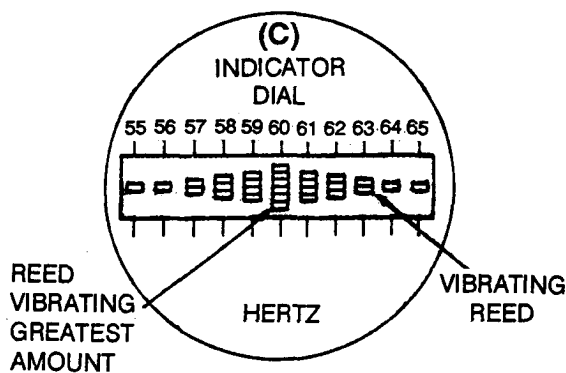
(A)  
CIRCUIT(B)  
REEDS

FIGURE 9-29. Simplified Diagram of a Vibrating Reed Frequency Meter.

In some instruments, the reeds are the same lengths but are weighted by different amounts at the top so that they will have different natural rates of vibration.

The indicator dial of Figure 9-29 view C shows an end view of the reeds. If the current has a frequency of 60 hertz, the reed marked 60 hertz will vibrate the greatest amount, as shown.

### Moving Disc Frequency Meter

Moving disc frequency meters can be found in out-of-circuit meters as well as in-circuit meters. Figure 9-30 shows a moving disc frequency meter. One coil tends to turn the disk clockwise, and the other, counterclockwise. Magnetizing coil A is connected in series with a large value of resistance. Coil B is connected in series with a large inductance, and the two circuits are supplied in parallel by the source.

For a given voltage, the current through coil A is almost constant. However, the current through coil B varies with frequency. At a higher frequency, the inductive reactance is greater, and the current through coil B is less. The reverse is true at a lower frequency. The disc turns in the direction determined by the stronger coil.

A perfectly circular disc would tend to turn continuously. This is not desirable. Therefore, the disc is constructed so that it will turn only a certain amount clockwise or counterclockwise about the center position, which is commonly marked 60 hertz. To prevent the disc from turning more than the desired amount, the left half of the disk is mounted so that when motion occurs, the same amount of disc area will always be between the pole of coil A.

Therefore, the force produced by coil A to rotate the disk is constant for a constant applied voltage. The right half of the disk is offset, as shown in the Figure 9-30. When the disk rotates clockwise, an increasing area will come between the poles of coil B. When it rotates counterclockwise, a decreasing area will come between the poles of coil B. The greater the area between the poles, the greater will be the disc current and the force tending to turn the disk.

If the frequency applied to the ammeter should decrease, the reactance offered by L would decrease, and the field produced by coil B would increase. The field produced by coil A would remain the same. Thus, the force produced by coil B would tend to move the disk and the pointer counterclockwise until the area between the poles was reduced enough to make the two forces equal. The scale is calibrated to indicate the correct frequency.

If the frequency is constant and the voltage is changed, the currents in two coils, and therefore the opposing forces, change by the same amount. Thus, the indication of the instrument is not affected by a change in voltage amplitude.

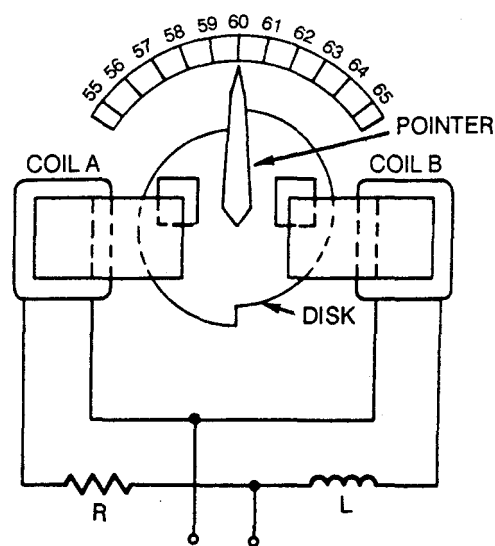


FIGURE 9-30. Simplified Diagram Of a Moving Disk Frequency Meter.